II.2 10-kW Solid Oxide Fuel Cell Power System Commercialization

Daniel Norrick
Cummins Power Generation
1400 73rd Avenue NE
Minneapolis, MN 55432
Phone: (763) 574-5301; Fax: (763) 528-7229; E-mail: Daniel.a.norrick@cummins.com

DOE Project Manager: Don Collins
Phone: (304) 285-4156; E-mail: Donald.Collins@netl.doe.gov

Subcontractors:
SOFCo-EFS Holdings LLC, Alliance, Ohio

Objectives

- The objective of the Cummins Power Generation (CPG) and SOFCo-EFS Holdings LLC (SOFCo) Solid State Energy Conversion Alliance (SECA) development program is to demonstrate the SECA Phase 1 solid oxide fuel cell (SOFC) objectives through technical progress in the following areas:
- SOFC stacks that achieve target performance, stability, and cost.
- Waterless catalytic partial oxidation (CPOX) reforming process that efficiently and cost-effectively converts natural gas or propane into a hydrogen-rich synthesis gas for mobile applications.
- SOFC hot box (an insulated enclosure containing SOFC stacks, manifolds, heat exchangers, start-up burner, and reformer) design that is compact and can be mass-produced at a cost meeting the SECA Phase 1 cost target.
- SOFC system balance of plant, including air and fuel supply systems, that meets the cost and reliability targets.
- A control system to manage the SOFC power system, including regulation of fuel and air flows, management of electrical power generation, and load sharing. The control system must operate in conjunction with an energy storage system through start-up, steady-state and transient loads, and shut-down, including emergency shut-down, without damage to the SOFC stack.
- An efficient electrical power conditioning system to convert DC voltages and invert to produce useable AC output.

Approach

The CPG-SOFCo approach coordinates development in the following major areas:

- Planar solid oxide fuel cell, ceramic interconnect, and stacks
- Planar SOFC manufacturing and scale-up for economic manufacturing
- Dry CPOX fuel reforming
- Fuel cell balance of plant (BOP)
- Fuel cell and power electronics system controls
- Power conditioning

Specifically, the CPG-SOFCo team is conducting the following work:

- Develop and evaluate advanced solid oxide fuel cells that provide the required performance and are compatible with the SOFCo ceramic interconnect.

- Conduct a progressive sequence of SOFC stack tests to validate development of materials and assembly methods for useable stacks that can achieve high fuel utilization (good sealing) and low degradation rates.
- Develop a CPOX reforming process and scale-up to system-sized units.
- Design and develop a hot box subsystem which can be delivered to CPG for integration into complete SOFC power systems.
- Develop control hardware and software required to regulate system operation.
- Integrate the BOP components, hot box subsystem, and controls into a working deliverable prototype. Initiate prototype operation with stack simulators for system shakedown, followed by installation of SOFC stacks and operation of the full prototype through the SECA Phase 1 test sequence.

Accomplishments

- Advanced scandia-stabilized zirconia (ScSZ) electrolyte-supported cells demonstrated improved cell performance.
- Degradation of short stacks was reduced to approximately 3% per 500 hours.
- Fuel utilization in excess of 80% with natural gas reformate was demonstrated, confirming the viability of SOFCo's stack assembly method and the materials used for seals and electrical contacts between the cells and interconnects.
- Dry (waterless) CPOX reforming for natural gas and propane was successfully demonstrated. The bench-scale CPOX reactor was scaled up for use in a 5-kilowatt-scale prototype system, demonstrated and characterized for carbon-free operation in the design operating range.
- Control hardware and software have been developed to provide steady-state and transient control of a SOFC system.
- A kilowatt-scale prototype (C1) operated for over 600 hours on natural gas reformate during characterization for system control design. Testing on the C1 prototype validated system models and control algorithms, and provided valuable information on system transient response.
- A 5-kilowatt, thermally integrated, four-stack hot box assembly comprising stacks, manifolds, recuperator, CPOX reformer, start-up burner, insulation, and structural housing has been designed and constructed for the C2 deliverable prototype.
- The C2 deliverable prototype balance of plant, including air and fuel supply systems, is nearing completion and scheduled to begin testing in August.
- Progress has been made with cost-effective BOP utilizing high-volume, low-cost, mass-production components from industrial and automotive sources.

Future Directions

- Refine the composition and microstructure of the electrodes for the advanced electrolyte-supported cell as required to achieve the Phase 1 target performance.
- Use instrumented short stacks and continued optimization of materials and stack design to assemble stacks that further reduce the non-cell contributions to resistance and power degradation rates.
- Complete the compilation of design information to support final cost estimating.
- Complete the final tailoring and development of the DC boosts for the fuel cell and battery system.
- Complete the development of the control system and integration with the fuel cell, balance of plant, and power electronics.
- Conduct the SECA Phase 1 evaluation test, including steady-state and transient evaluations, and report results to the National Energy Technology Laboratory (NETL) before shipping the unit to NETL for evaluation.

Introduction

Solid oxide fuel cell power systems offer the potential to generate electrical power from hydrogen or hydrocarbon fuels cleanly and efficiently. The objective of the CPG-SOFCo project is to design and develop a 3-10 kW SOFC-based power system that can be competitive with existing small diesel generating systems in terms of cost and package size, but offer significant benefits in efficiency, emissions, lower noise and vibration. Achieving these objectives requires advancement in five major areas:

- Cell, interconnect, and SOFC stack performance and robustness
- Optimizing manufacturing processes for production of cells, interconnects, and stack assemblies
- System design, thermal integration, and packaging of the hot components and sub-systems, including stacks, fuel reformer, and heat exchangers, and insulation system
- Control system for regulating air and fuel flows to the stacks in proportion to electrical load and operating temperatures, and for managing electrical load distribution between the fuel cell and batteries during steady-state and transient loading
- Electrical power conditioning, including DC voltage boosts (converters) and DC to AC power (inverter)

The team has made significant progress in all five areas during 2005 and is on schedule to meet the objectives of Phase 1 of the SECA program.

Results

Development work has continued to improve cell performance, primarily through the development of scandia-stabilized zirconia electrolytes to improve ionic conductivity and reduce cell area-specific resistance (ASR). Through this work, ASRs have been reduced and are approaching the Phase 1 target value (Figure 1).

In addition to improvements in cell and stack ASR, stacks have been developed to provide improved degradation performance. The linkage between cell improvement and stack improvement is illustrated in Figure 2. Typical stack power degradation at constant voltage has been improved to 3% per 500 hours (Figure 3), nearing the Phase 1 target of 2% per 500 hours.

Carbon-free dry (waterless) CPOX reforming for natural gas was successfully demonstrated. A kilowatt-scale CPOX reactor was scaled up for use in the 5-kilowatt deliverable system. Long-term testing with natural gas showed carbon-free stable operation, and stacks operated on the reformate demonstrated no problems through extended testing.

A progression of stack tests have validated the stack assembly process and the integrity of the stack sealing system. Stacks of up to 70 cells have been constructed and tested. A typical 70-cell stack installation in a stack test fixture is shown in Figure 4. Target fuel utilization of 80% has been demonstrated on stacks of all sizes.

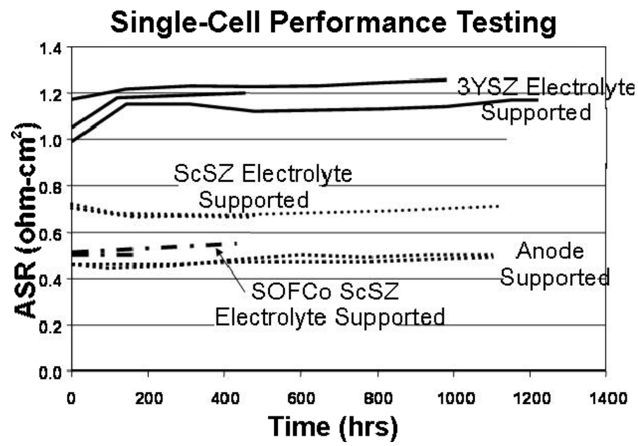

Figure 1. Progressive ASR Reduction

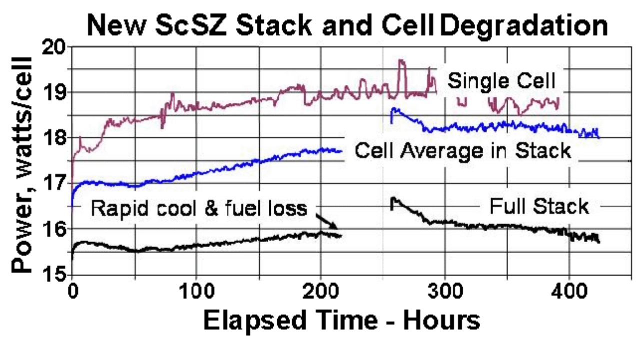

Figure 2. Cell Improvement in Stacks

Figure 3. Improved Stack Degradation

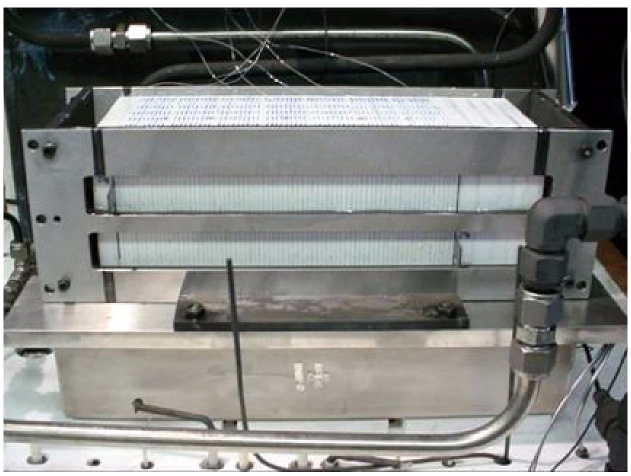

Figure 4. 70-Cell Stack in Stack Test Fixture

Design and manufacturing work to scale-up the ceramic interconnect from approximately 10 by 10 cm to 15 by 15 cm has demonstrated the ability to produce high-quality parts meeting design requirements at lower specific manufacturing costs.

Testing of a kW-scale demonstrator unit at CPG in Minneapolis has provided valuable information validating system modeling and control strategy. During testing, CPG-developed controls exhibited excellent steady-state and transient stability and response.

CPG demonstrated a high-efficiency inductor-based DC-DC boost system which will be used to control current flow and voltage supply to the inverter section from the fuel cell stacks and from the batteries. A second transformer-based DC-DC bi-directional boost is developed to provide and regulate a mix of energy flows from the fuel cell and the system's battery pack.

Conclusions

- Electrolyte-supported cells with ScSZ electrolytes provide improved SOFC performance.
- Planar SOFC stacks in the range of 70 repeat units can be constructed and successfully operated at high fuel utilizations.
- A dry (waterless) catalytic partial oxidation reformer system can provide a suitable fuel stream from commercial natural gas without sulfur removal and without forming carbon.
- A compact kilowatt-scale SOFC power system can be started and operated within design parameters in both steady-state and transient operating modes.

FY 2005 Publications/Presentations

1. "Planar SOFC Stack with Low-Cost Multi-Layer Ceramic Interconnect", Z. Liu, E. Barringer, R. Goettler, Ninth International Symposium on Solid Oxide Fuel Cells (SOFC IX) in Quebec City, Canada, May 17, 2005 (available at www.sofco-efs.com).
2. K. Kneidel et al, "Development of SOFC Power Systems Using Multi-Layer Ceramic Interconnects", 2004 Fuel Cell Seminar Abstracts, pp.109-112., November 2004.
3. D. Norrick, "10kWe SOFC Power System Commercialization Program Progress", SECA Annual Workshop, April 20, 2005, Monterey, CA (available at www.cummins.com).